DUSEL Beamline Working Group Report

DUSEL Collaboration Mtg, UC Davis, 2/27/09

Mary Bishai
for the Beam Working Grp (BNL, FNAL)

February 27, 2009

Outline

Goals of the DUSEL BL Working Group

Produce a conceptual design by 2010

CD1 objectives: define requirements and evaluate alternatives

We have been charged by DOE to produce the plan for getting to CD1 by March 09 (Gina et. al):

1.1 Technical Components
- 1.1.1 Primary Beam
- 1.1.2 Target Hall Components
- 1.1.3 Decay Tunnel and Absorber
- 1.1.4 Radiological Shielding and Control
- 1.1.5 Infrastructure and System Integration

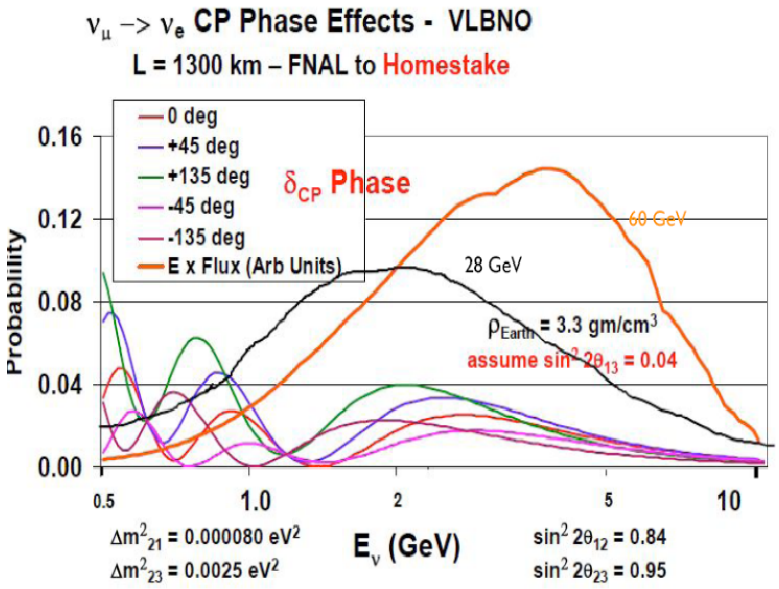
1.2 Civil Construction
- 1.2.1 Site Preparation
- 1.2.2 Tunnels and Halls
- 1.2.3 Service Buildings and Outfitting

1.3 Beam Instrumentation and Near Detector
- 1.3.1 Specification and Design
- 1.3.2 Construction
- 1.3.3 Installation

Work summarized here addresses portions of 1.1.1,1.1.2,1.1.3, 1.2.1 and 1.2.2

Requirements of the FNAL/Homestake Beam

The design specifications of a new WBLE beam based at the Fermilab MI are driven by the physics of $\nu_\mu \rightarrow \nu_e$ oscillations:



L = 1300 km

Requirements:

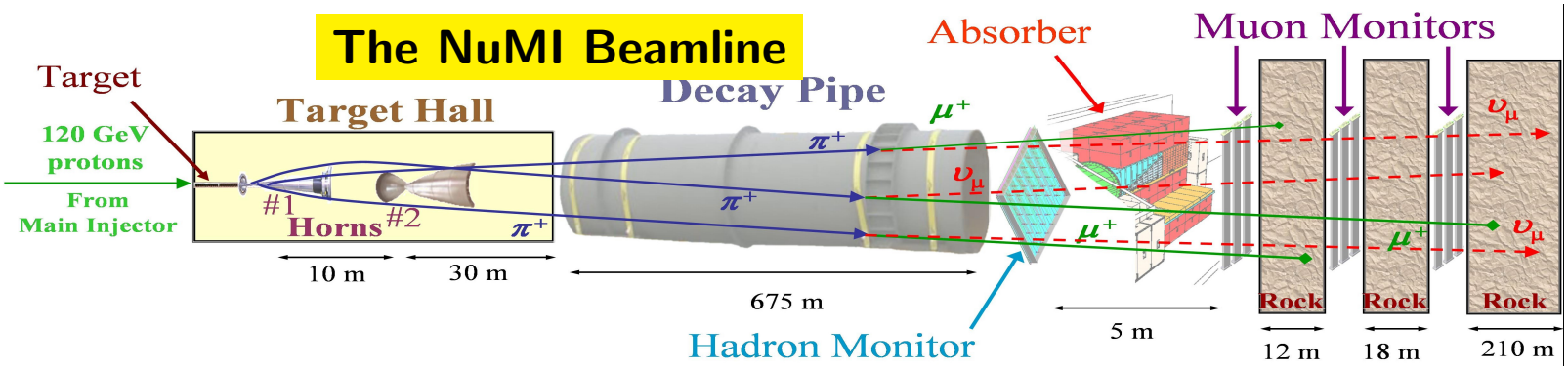
-Maximal possible neutrino fluxes to encompass the 1st and 2nd oscillation nodes, with maxima at 2.4 and 0.8 GeV.

-High purity ν_μ beam with negligible ν_e

-Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV is highly desirable. MINOS long-baseline $\nu_\mu \rightarrow \nu_e$ search finds (results announced TODAY):

$$\frac{\text{NC from tails}(>5\text{GeV})}{\text{All NC}} \sim 0.5 - 0.6$$

DUSEL Beam design options



- **Strategy 1:** Increase low energy flux at the oscillation maximum through improved:

  1a) target design
  1b) focusing
  1c) beam energy
  1d) decay pipe geometry

- **Strategy 2:** Improve S:B at low energies by reducing high energy tail using:

  2a) beam energy 2b) beam plugs,
  2c) off-axis beams

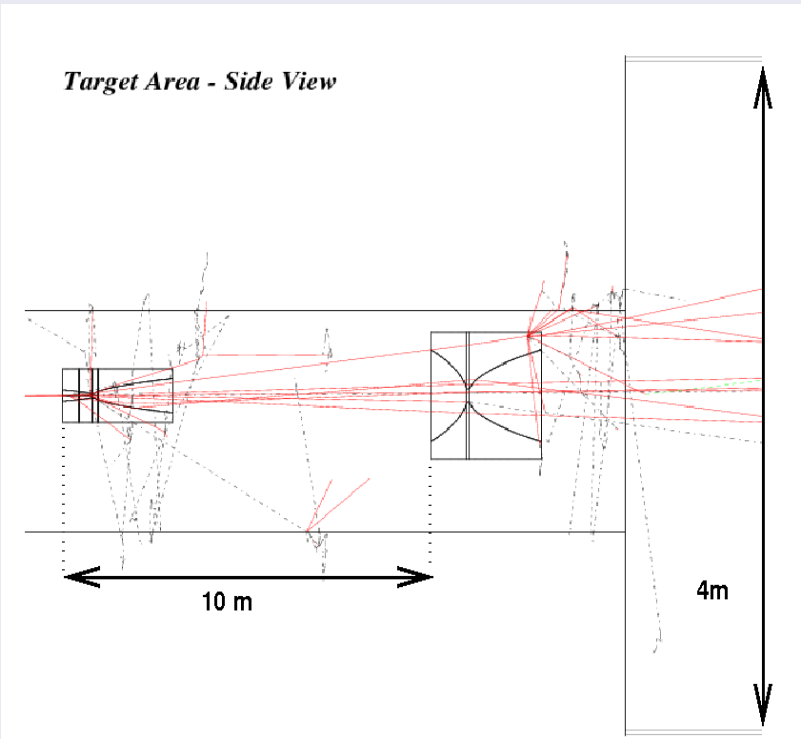
— Needs work — 50-80% done — > 80% done

Focusing/targeting system studies

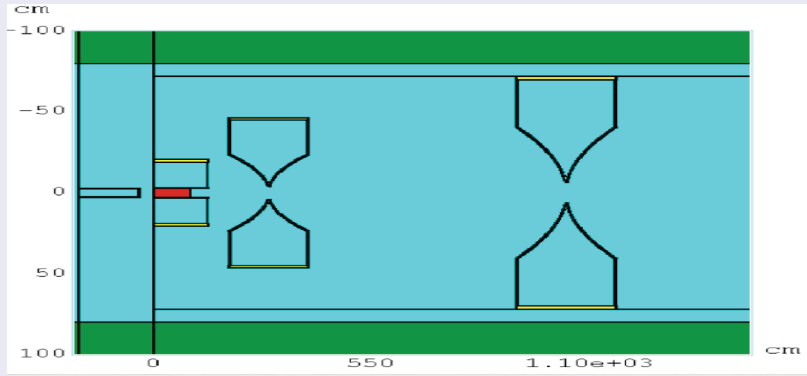
Focusing system alternatives

Two *INDEPENDANT* efforts on focusing system designs

M. Bishai Fluka05/GEANT3 (NuMI)



B. Lundberg MARS (T2K)

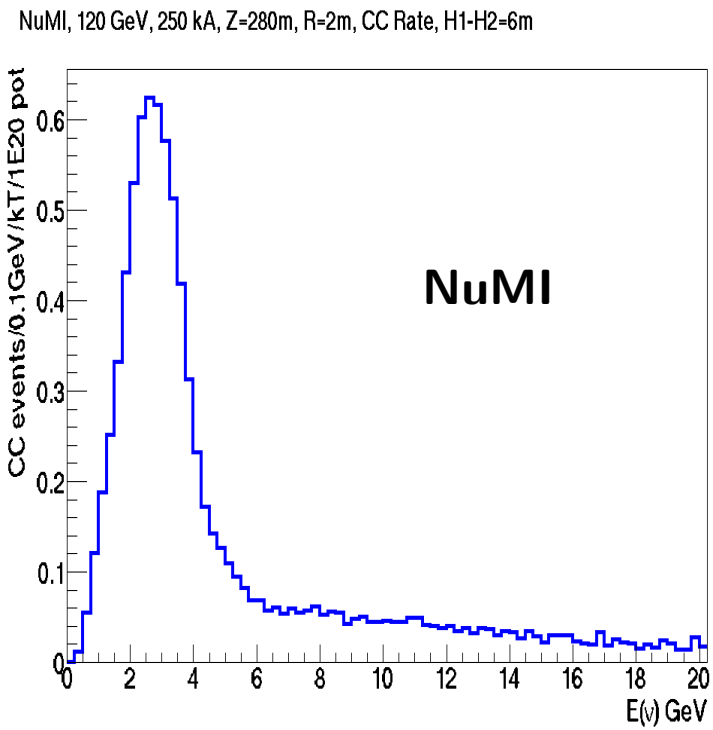


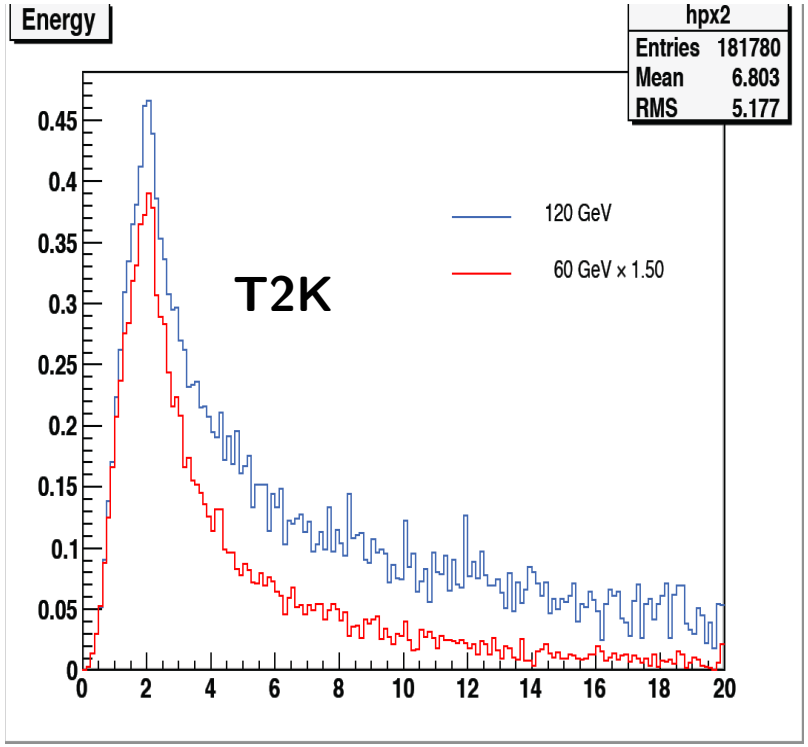
Both designs use fully embedded carbon targets and similar horn 2

In a 2 horn system, optimal separation = 6m (both designs)

Beam spectra from 2 alternatives

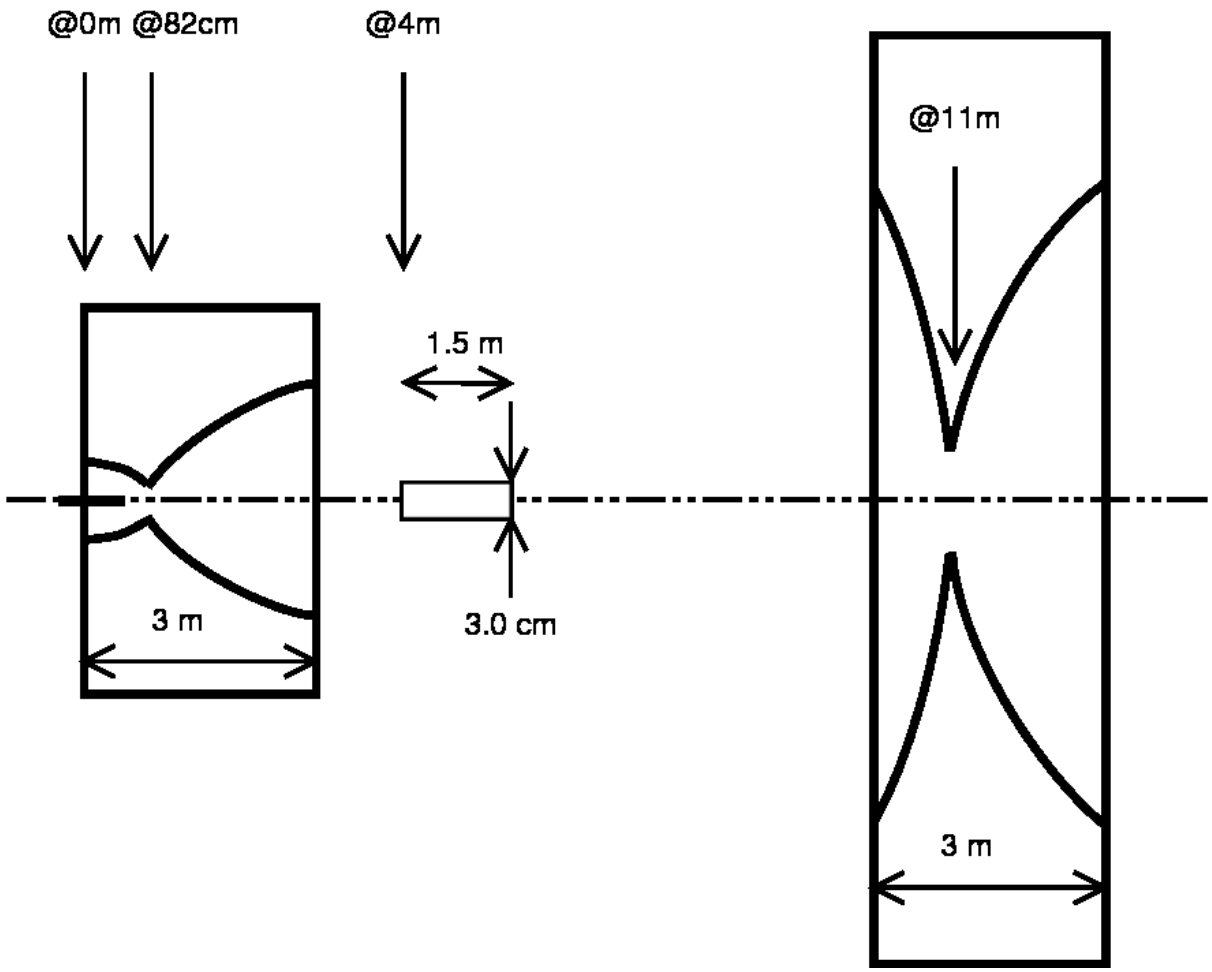
Using a decay pipe of 4m diameter and 250/280m (T2K/NuMI) decay length ON AXIS flux :





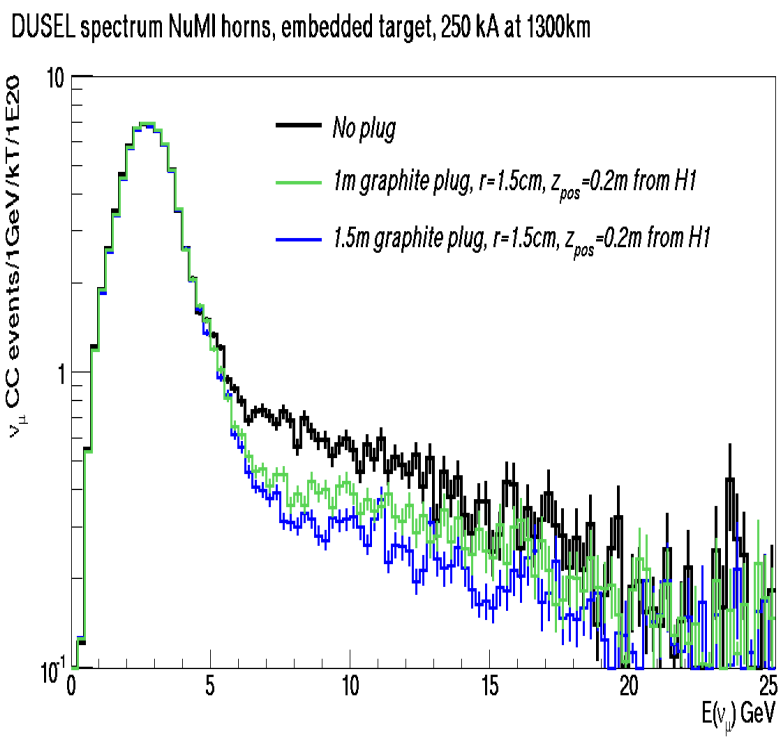
Simulation 120 GeV	0.8 GeV Rate	Peak Rate (E)	6 GeV Rate
	CC events/GeV/kT/1E20 pot at 1300km		
NuMI	1.7	4.6 (2.0 GeV)	0.6
T2K	1.2	6.2 (2.4 GeV)	1.3

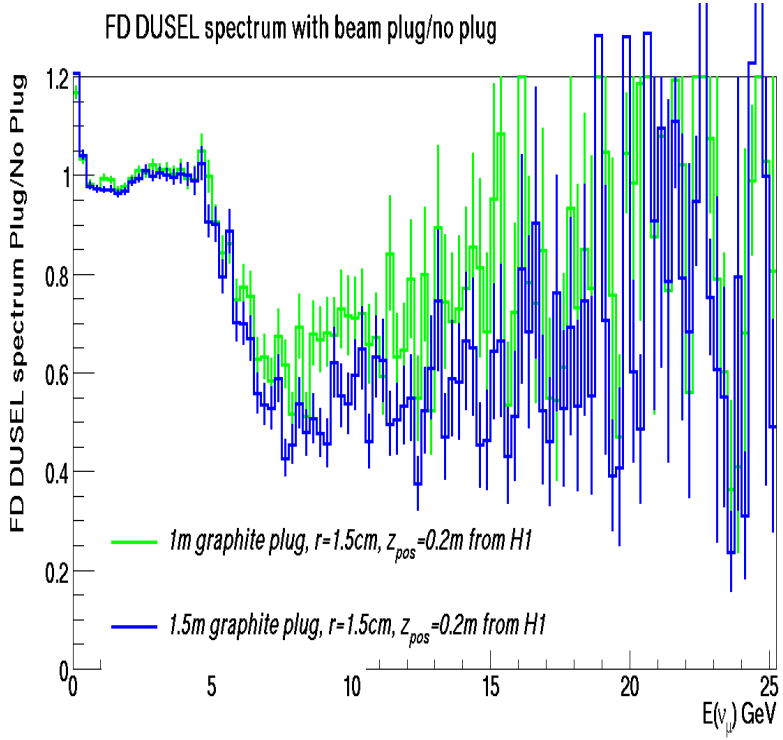
Whats a beam "plug"?



In 2001, Brett Viren (following up on studies at IHEP) found that a 1.5cm radius graphite target placed between the 2 horns reduced the high energy tails in NuMI LE beam by $>$ 30 %.

DUSEL/NuMI spectra with different plugs





With 1.5m plug

$$\frac{\text{plug}}{\text{no plug}}(> 5\text{GeV}) = 0.62 \qquad \frac{\text{plug}}{\text{no plug}}(< 5\text{GeV}) = 0.99$$

Beam plugs Pros and Cons

Pros:

- **Most effective tool that reduces the HE flux exactly where you need it $>$ 5 GeV without any impact at low energy.**
  Current design reduced NC background in WCC simulaton by -18%
- **Might give you more ν at very low energies $<$ 0.5 GeV - good for solar oscillations.**
- **Tunable - different plugs can be used.**

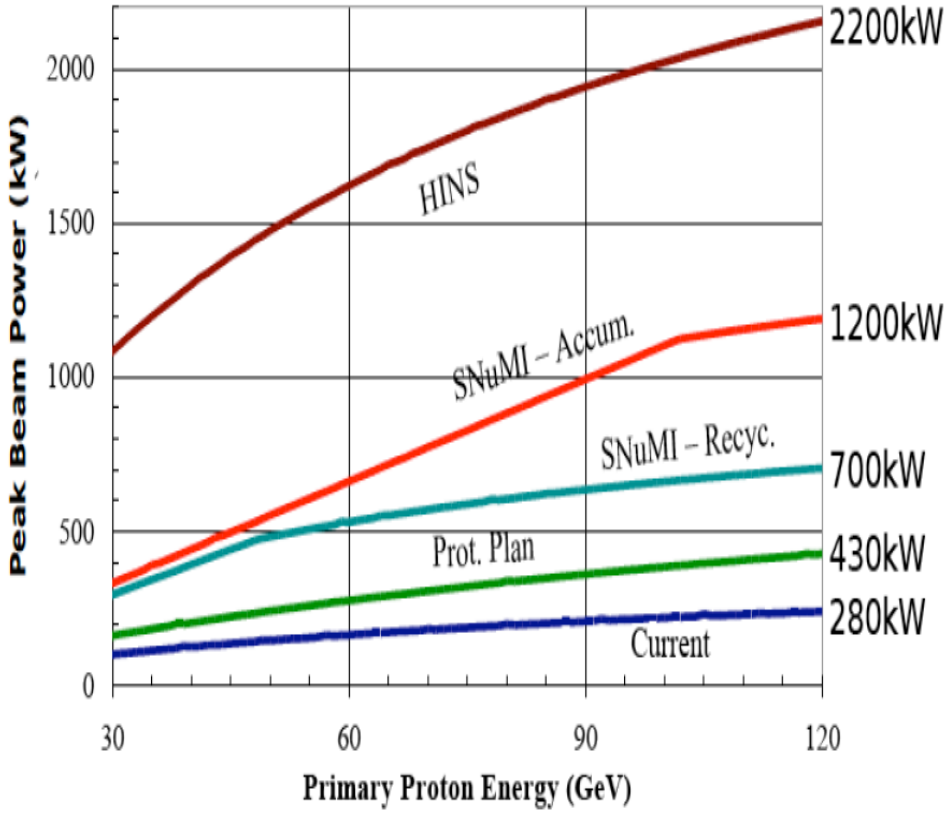
Cons:

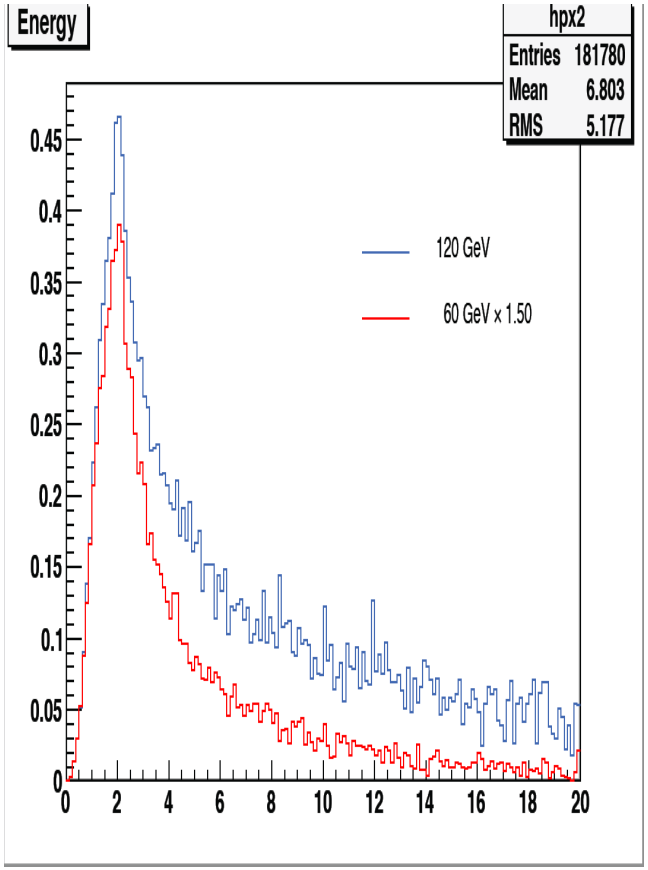
- **Requires expensive material R&D and engineering**
- **Complicates operating - need to change out plugs.**
- **Complicates beamline geometry for Near-Far extrapolation**

May not be necessary at lower primary beam energies

Proton beam energy optimization

Impact of primary proton energy on spectrum



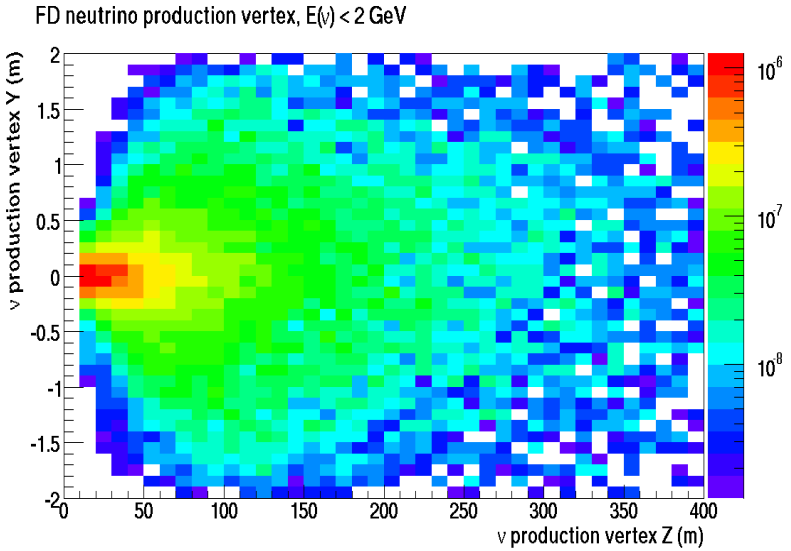


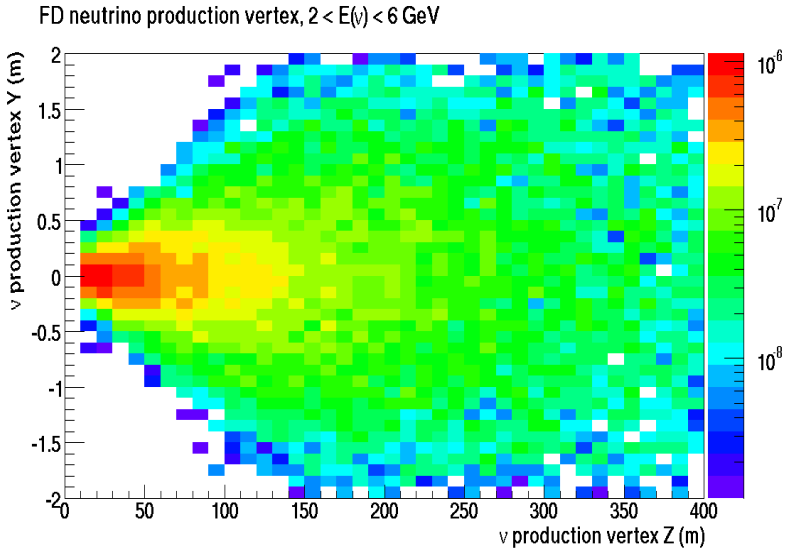
Lowering the beam energy is very effective at reducing HE tails and increases flux at lower beam energies - BUT we lose power!

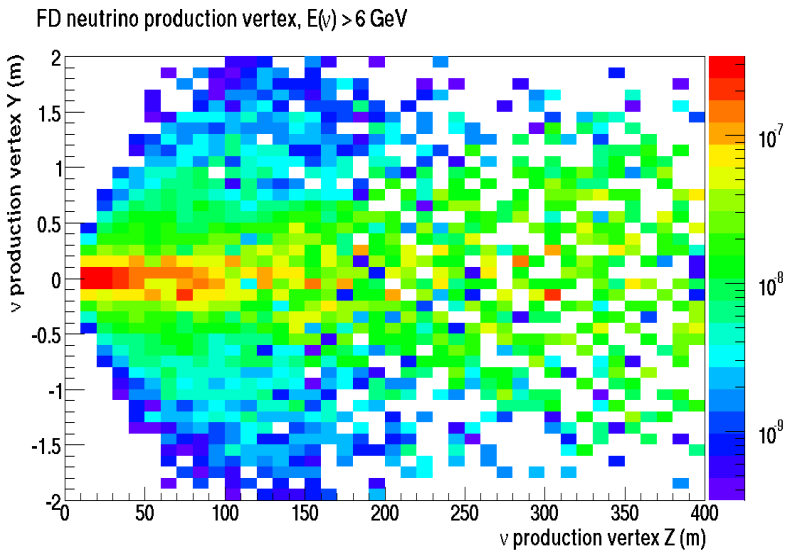
Design beamline to operate at 60-120 GeV. Optimize design at 90 GeV

Decay pipe optimization

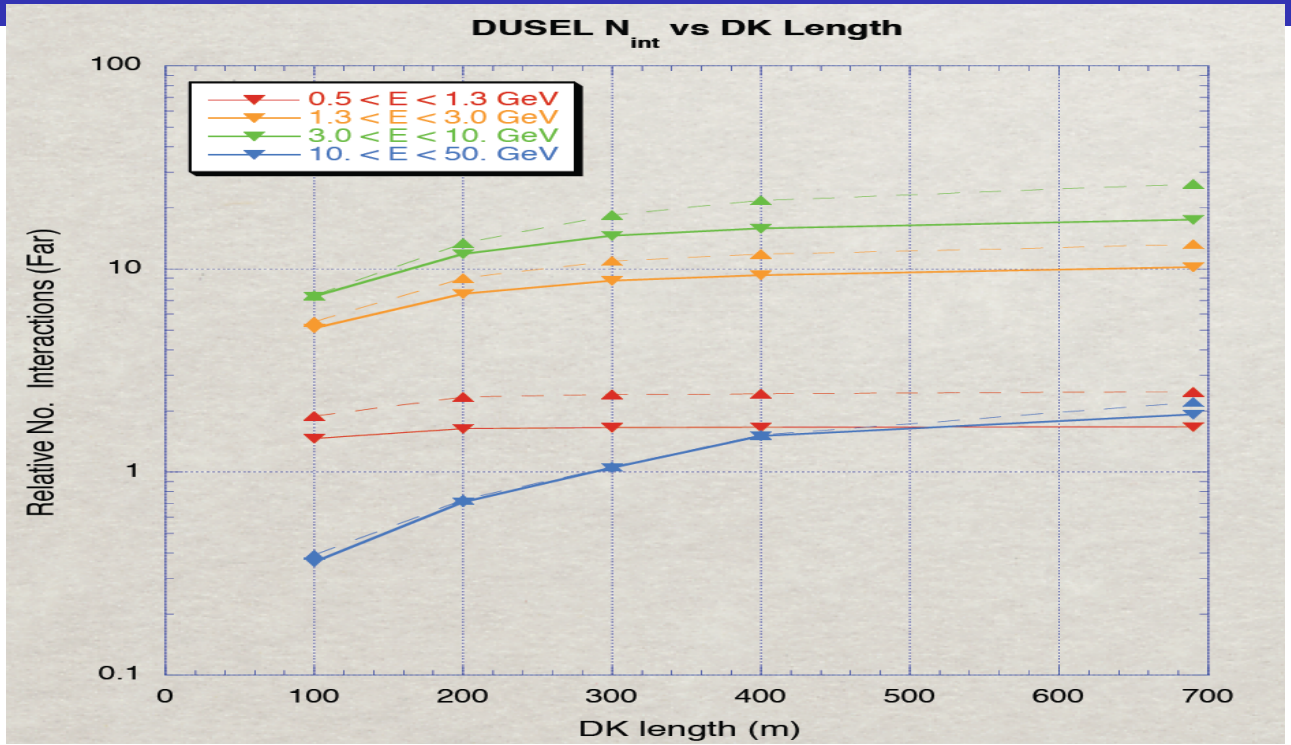
Decay pipe shape optimization







Decay pipe dimensions

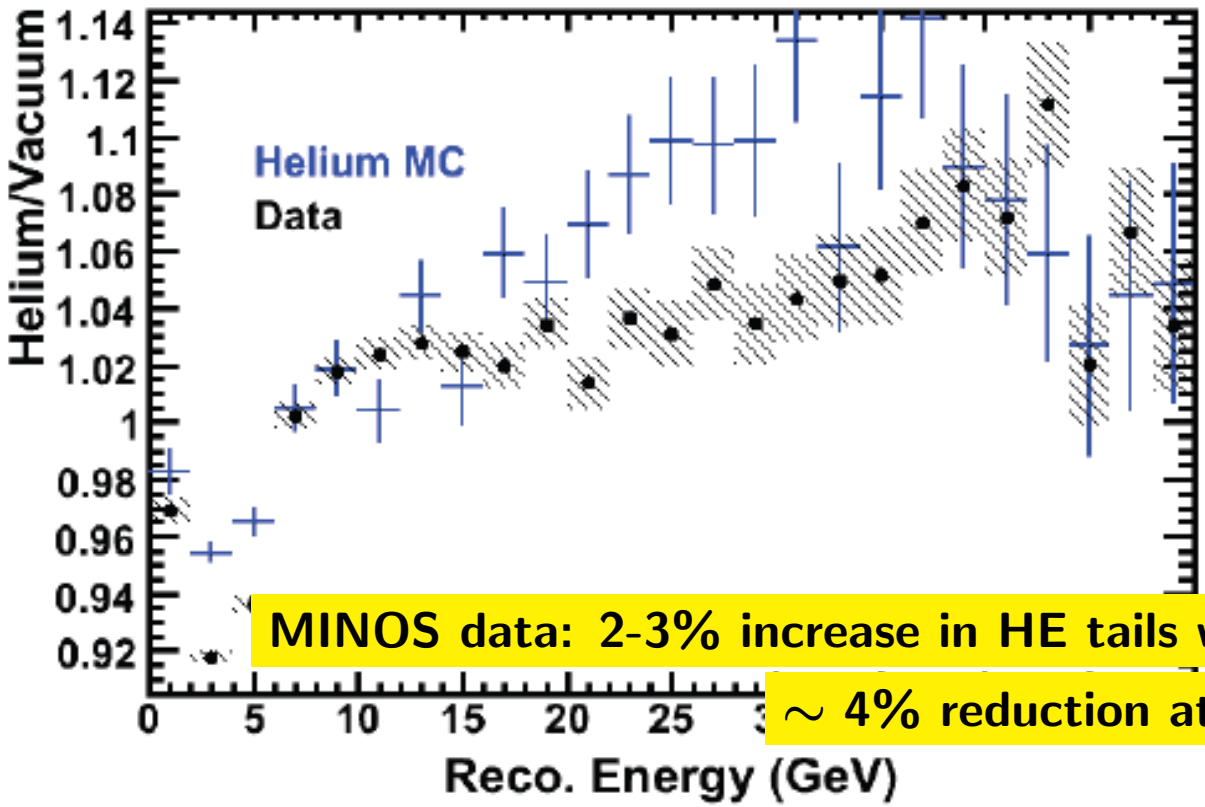


DP length	Rate $0-2$ GeV	Rate $2-6$GeV	Rate >6GeV
180m	3.1	11	6.3
280m	3.5	14	8.1
380m	3.6	16	9.7
480m	3.7	17	11
580m	3.7	17	11

Decay pipe dimensions: 2m radius, 300 $\pm$ 50 m length

What do we fill the decay pipe with?

- **The decay pipe was the single most expensive element in the NuMI beamline. An evacuated DUSEL decay pipe $\equiv$ \$ \$ \$**
- **To reduce costs, design a gas filled decay pipe at $\sim$ 1 atm.**



MINOS data: 2-3% increase in HE tails with He

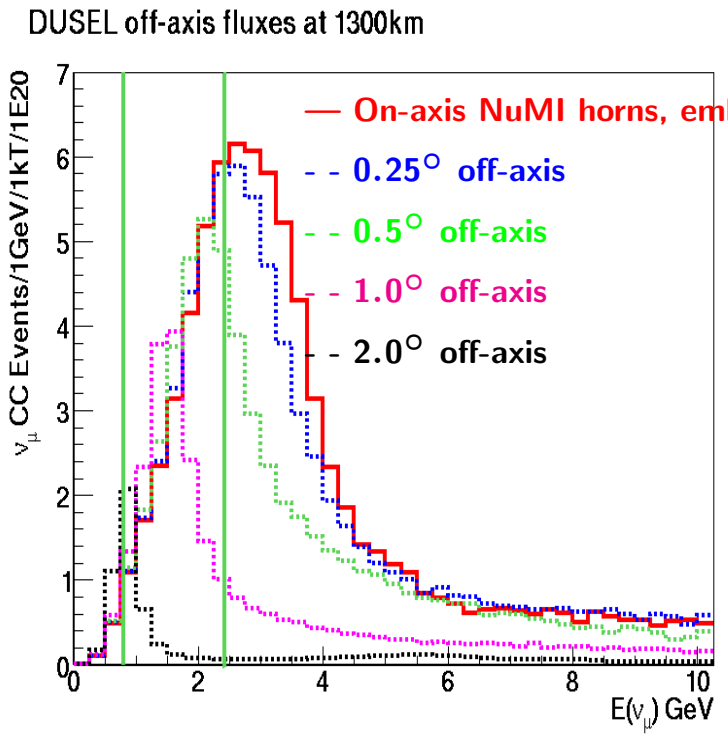
$\sim$ 4% reduction at 3 GeV

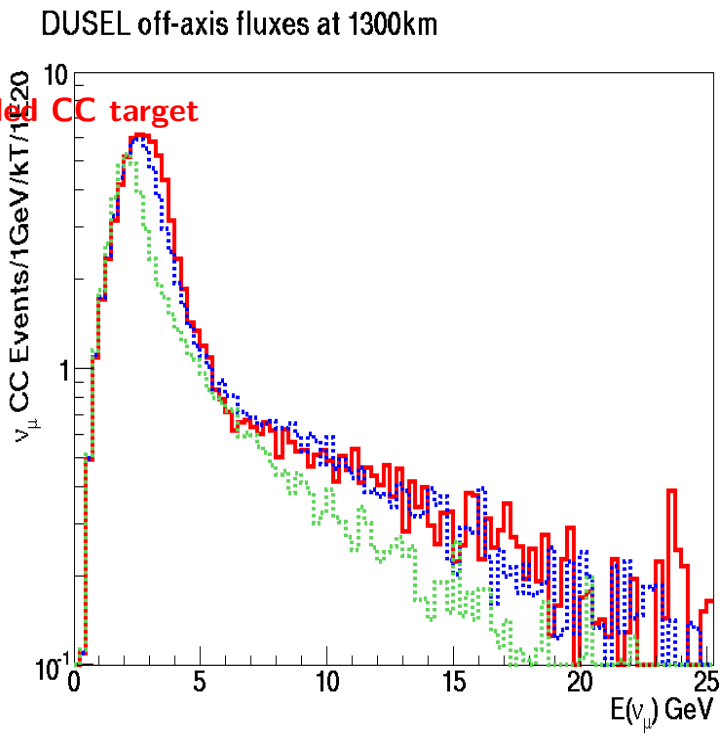
Nitrogen = 13% more heat in DP walls, 15% loss at peak (3 GeV)

Going off-axis

Going off-axis

Another alternative to cutting down the high energy tails is going off-axis - redo calculation with optimized on-axis beam:





On axis flux is best for broad-band coverage

Off-Axis Pros and Cons

Pros:

- **Effective at reducing HE tails.**
- **At high angles $> 1^\circ$ enhances flux at the 2nd oscillation maxima.**
- **NuMI/MiniBoone data confirms simulation predictions off-axis**

Cons:

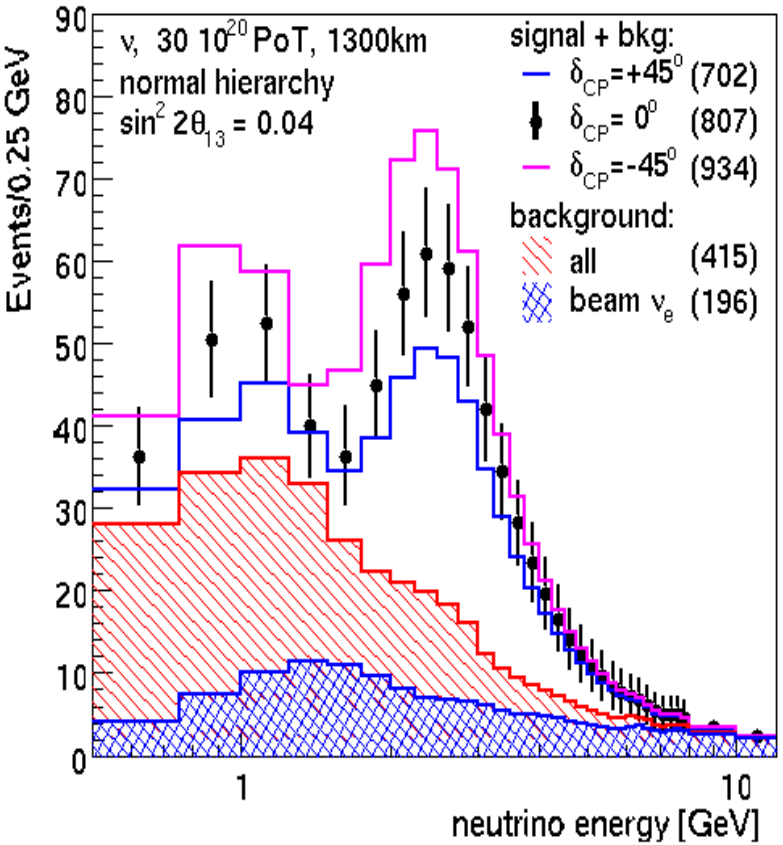
- **Throwing away beam flux at 1st osc maximum**
- **Limited tunability - WE CANT MOVE THE BEAMLINE!**
- **Limited broad-band spectrum.**

WCC spectra with current beam designs

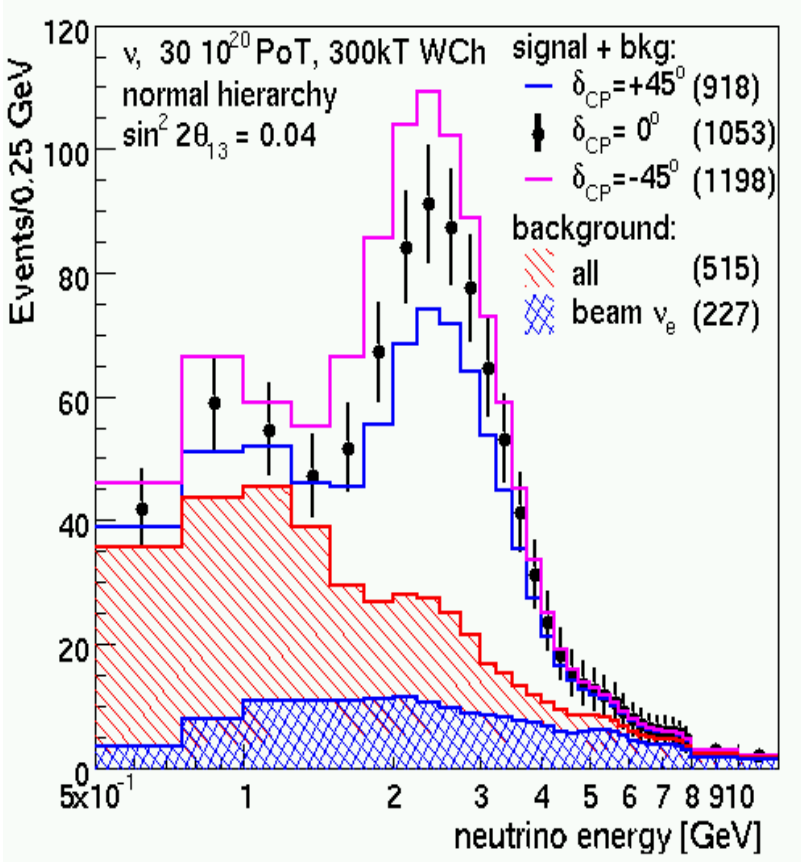
Mark Dierckxsens

Embedded CC target in NuMI horns with 6m separation, cylindrical decay pipe with 4m diameter, 380m length, 120 GeV beam.

Old DUSEL design



New design



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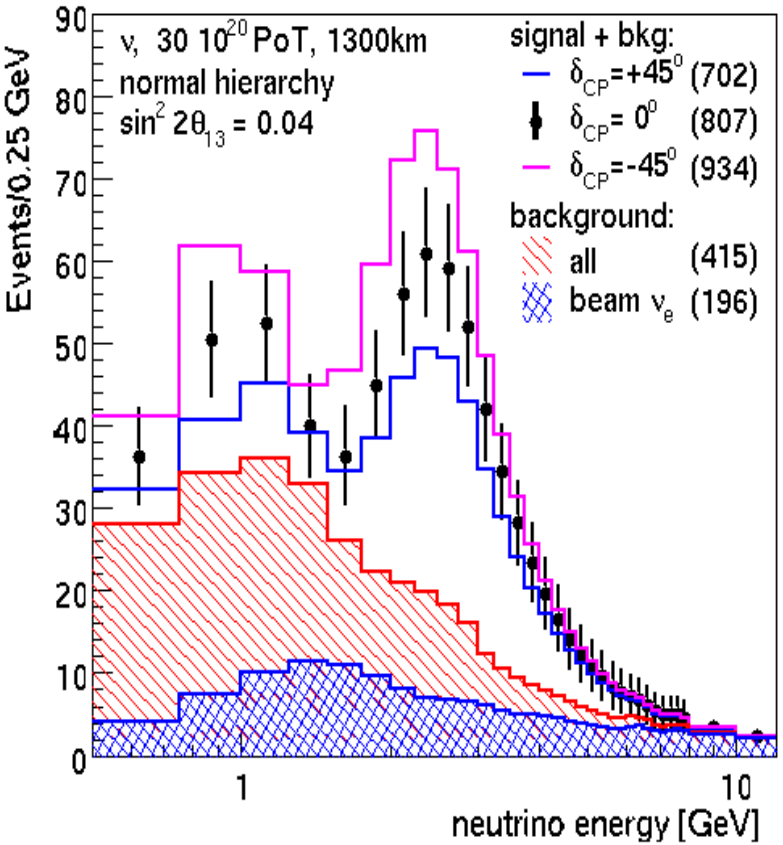
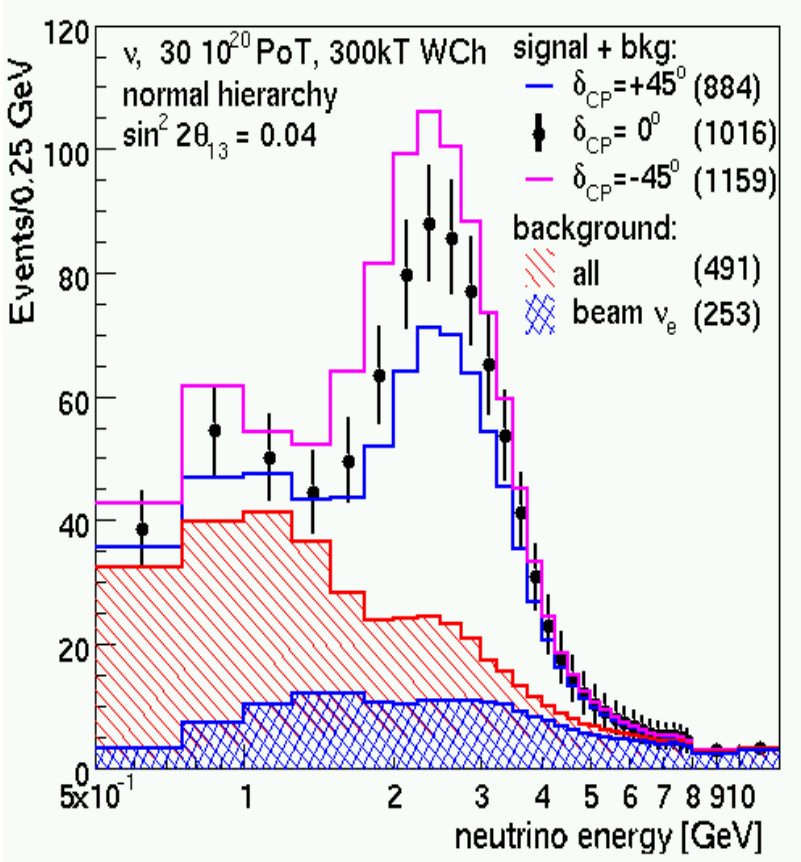


add plug



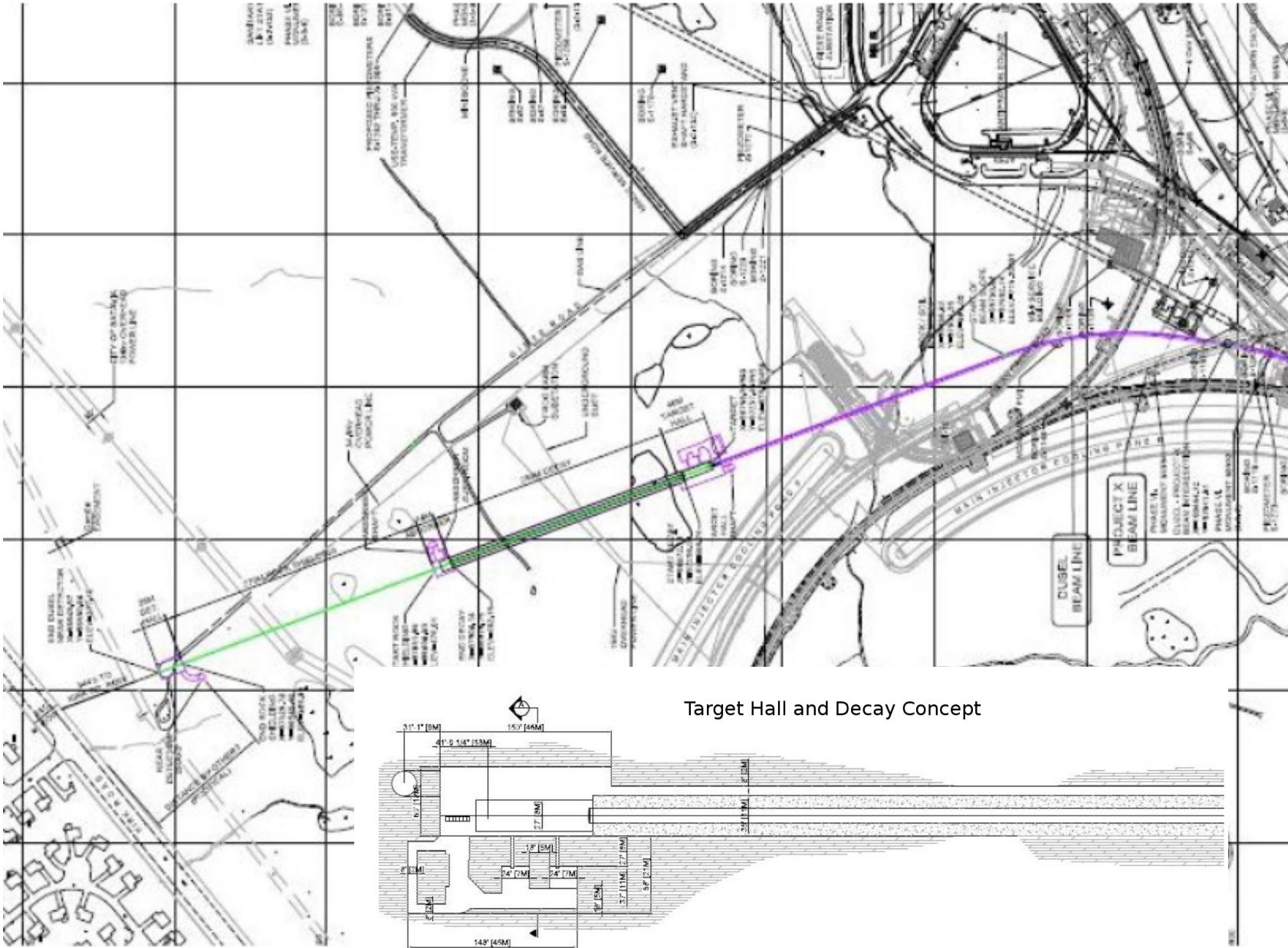
Summary from Weekly Civil Coordination Meetings

Goals:

- **Establish preferred facility layout**
- **Obtain first level understanding of facility construction costs and duration.**
- **Prepare civil design portion of CDR**

Conceptual Facility Layout

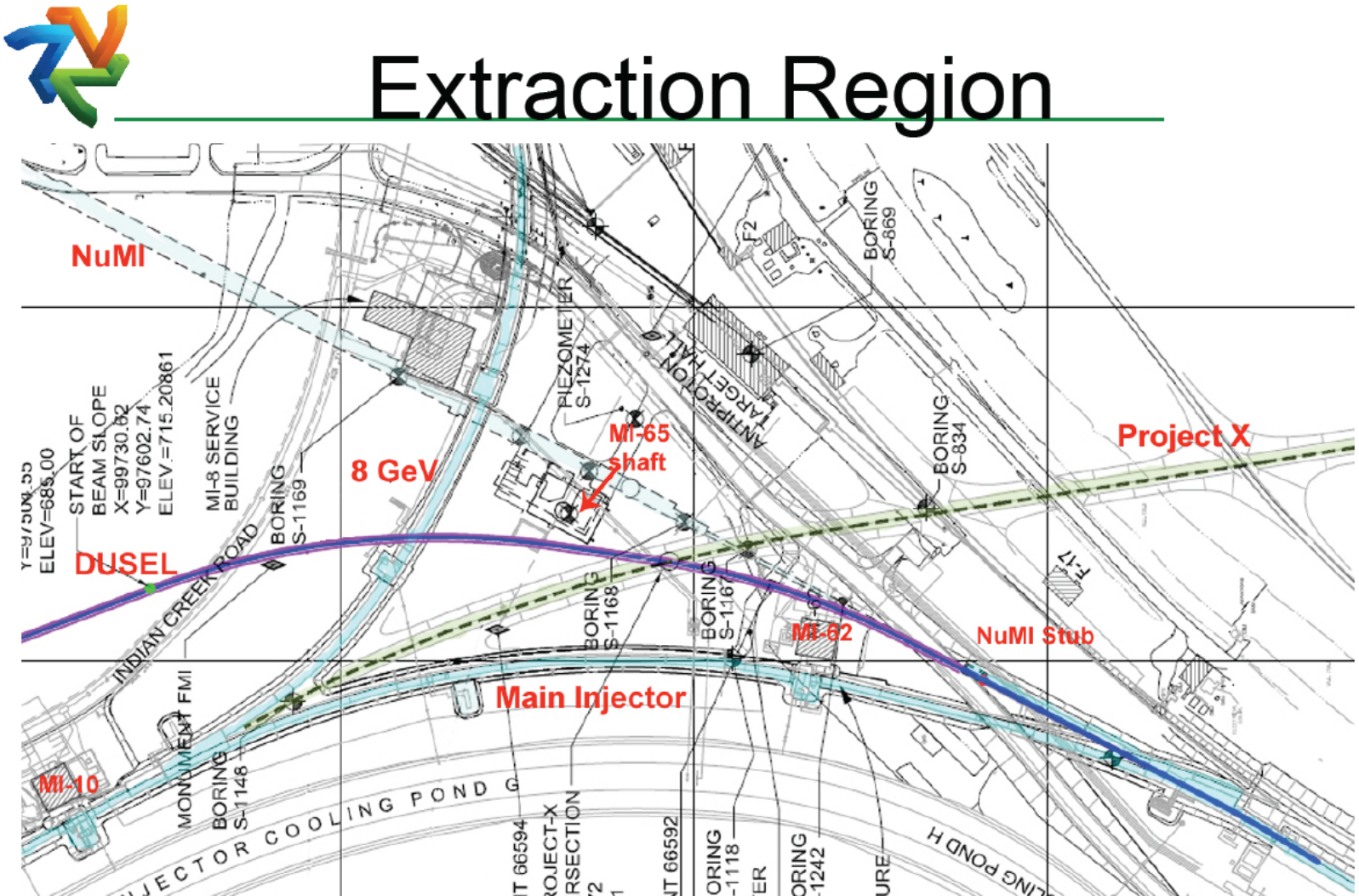
Sam Childress



Converging on extraction region

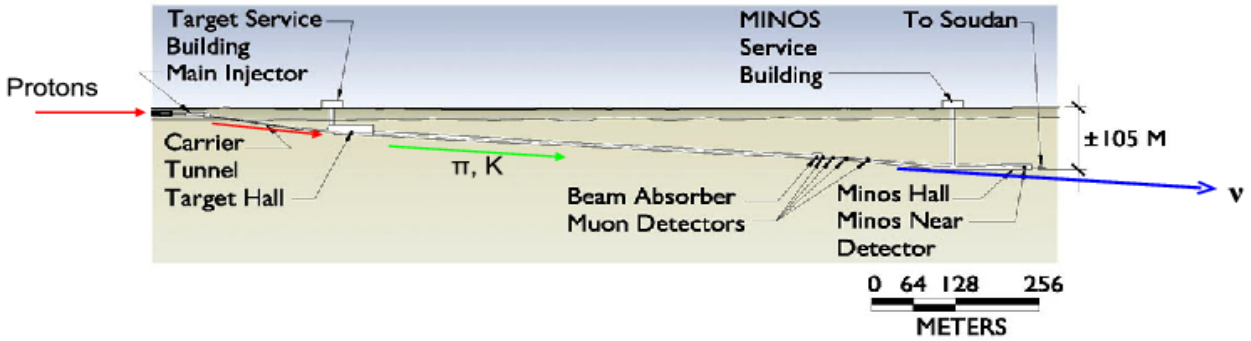
Peter Lucas

At least 3 proton beam extraction and bending to the west options have been eliminated. The current best choice is use NuMI extraction then bend to the west:



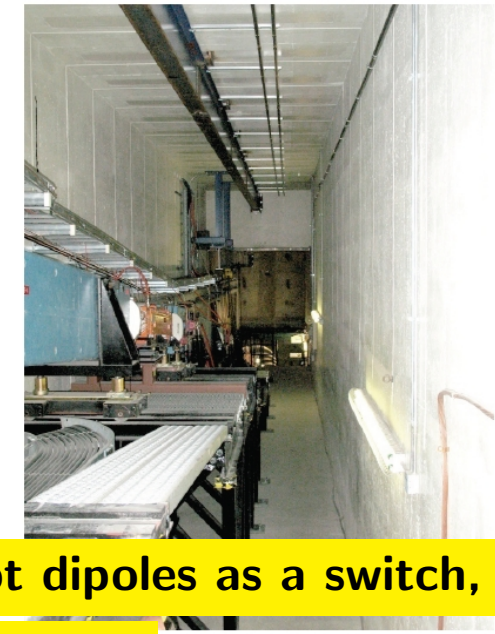
Scheme for keeping NoVA line intact

Peter Lucas



View looking upstream and uphill. DUSEL beam above and slightly left

Looking downstream and downhill. DUSEL beamline (mostly just pipe) near ceiling



Solution: Use two wide-aperture 10 foot dipoles as a switch, bend dusel and exit NuMI enclosure before carrier tunnel

Summary and Conclusions

Summary

The DUSEL beam working group has been meeting weekly for 6 months under the leadership of Jeff Appel (appel@fnal.gov)

- **EXTENSIVE post-evaluation and documentation of lessons learned from NuMI (physics performance, civil construction, radiological control, legal, project management....):**

  http://beamdocs.fnal.gov/SNuMI-public/DocDB/DocumentDatabase

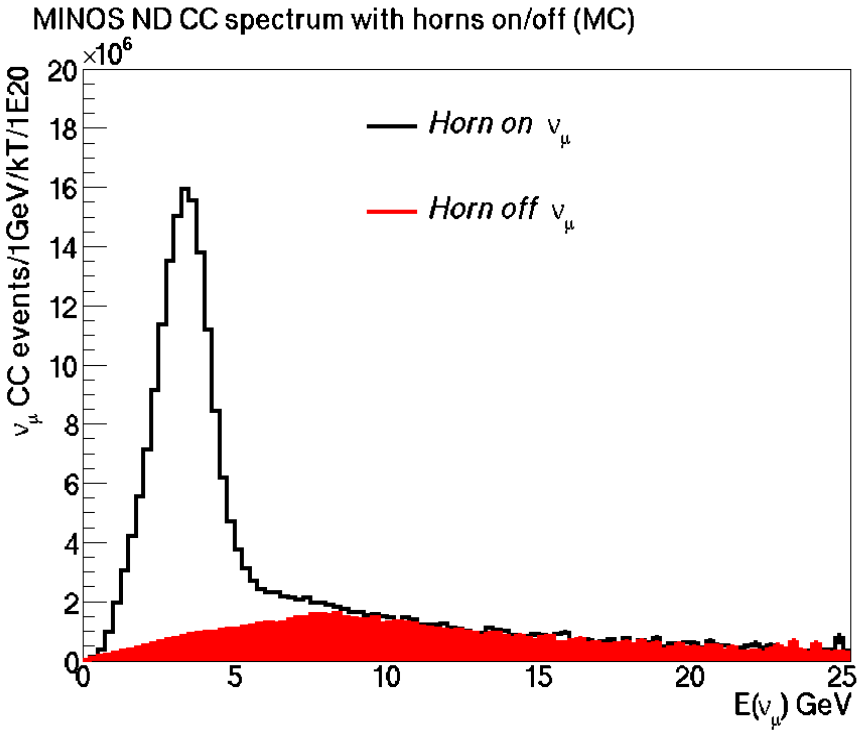
- **Detailed studies of two targeting and focusing system designs. We have LO designs that can do the physics!!. *But only simulated not engineered*.**
- **Consensus on dimensions of gas filled decay pipe for input to civil: DP $\sim$ cylindrical, r $= 2^{+0.5}_{-0.2}$ m, l $= 300 \pm 50$ m.**
- **We have also determined that the target hall length is $<$ 20m - details are now up to engineering, civil construction.**
- **Primary proton beam power: 90 ± 30 GeV. We have a preliminary primary beam extraction, transport, and semi-detailed layout.**

Getting to CD1

- **We need targeted engineering and material R&D on target/horn material for 2 MW beam and embedded targets.**
- **Converge on 1-2 conceptual designs for targeting/focusing.**
- **Physics driven decision SOON on air/He in decay pipe for input to engineering design.**
- **Build on the NuMI lessons learned to produce a conceptual design of radiological shielding and control.**
- **Finalize a conceptual layout of the whole facility, with buildings and shafts.**
- **Converge on final extraction layouts with the option of preserving NuMI/NOνA.**

For further discussion

NC backgrounds in the MINOS ND Data



In the MINOS ND data we measured the background composition of ν_e selected events with horn on/off in the region 1-8 GeV.

SEE MAYLY SANCHEZ's W&C TALK TODAY.

$$\frac{\text{NC from tails}}{\text{All NC}} \sim \frac{\text{NC horn off}}{\text{NC horn on}} \sim 0.5 - 0.6$$

Summary - lowering backgrounds

HE tails contribute 50-60% of NC background for ν_e appearance

HE tail ($>$ 5 GeV) adjustments to Fluka05 MC

Adjustment	Effect	Comment
MINOS beam fit (Data)	$\sim$ +20%	10% more flux at $<$ 5 GeV
He in beampipe (Data)	+3%	different beampipe geometry
1.5 m graphite plug (MC)	-38%	LE unchanged
0.5° off-axis (MC)	-38%	Less coverage at 1st maxima
p-beam 120 $\rightarrow$ 60 GeV	$-$46%**	At the same power

** Estimated using AGS focusing not NuMI

With 120 GeV protons, plug is the best option for lowering HE tails

Summary - improved performance

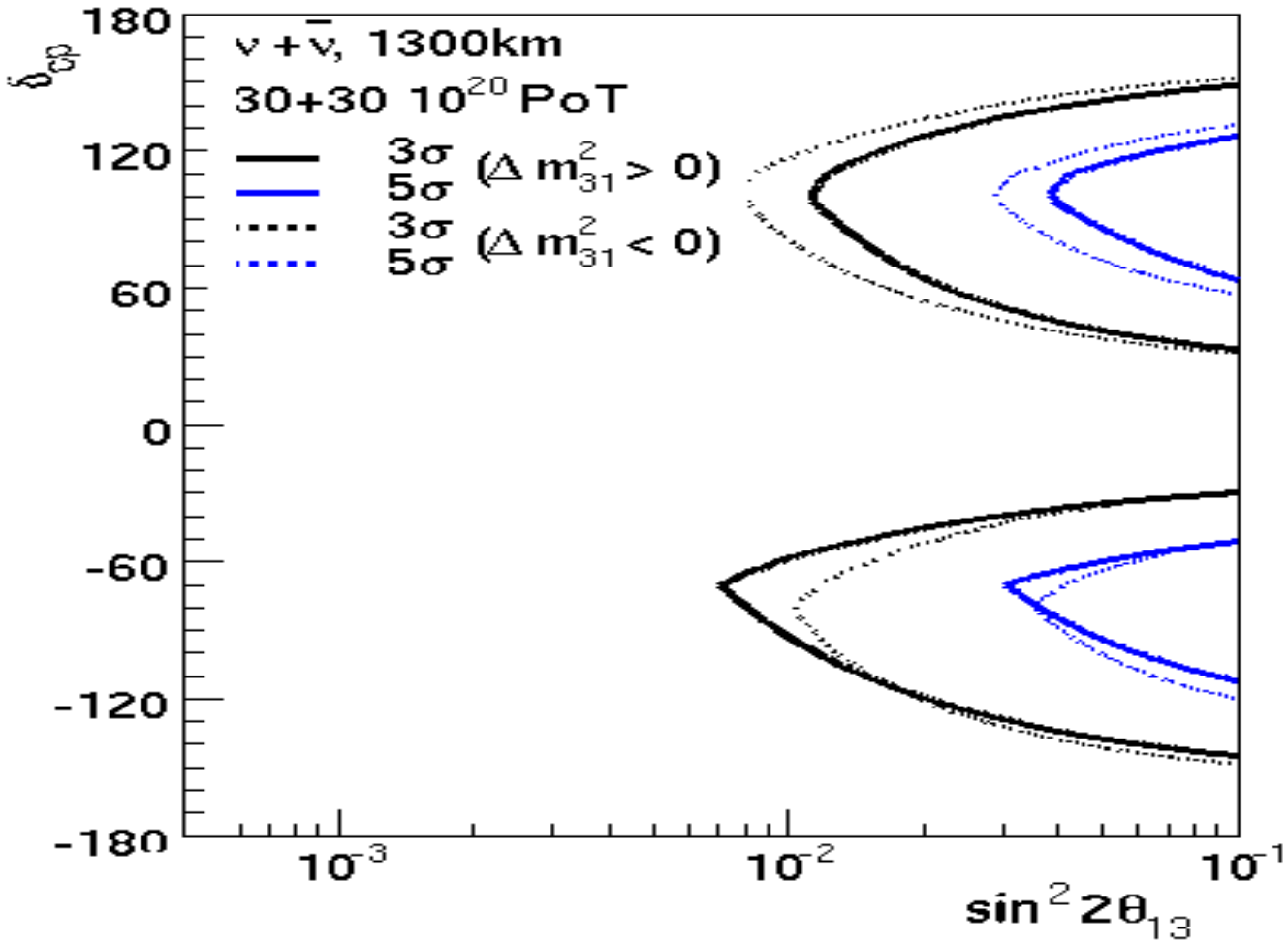
Signal type	Old oa flux	New focusing	With plug
ν_e signal δ_{cp}=+45	295	403	393
ν_e signal δ_{cp}=0	395	538	525
ν_e signal δ_{cp}=-45	509	683	669
NC bkgd	202	273	224
beam ν_e bkgd	196	227	253
numu	15	15?	15

Flux in the signal region by 30% compared to previous designs

- Used NuMI horns (known performance) and optimized current and alignment for DUSEL beam.
- Fully embedded target into Horn 1
- Increased horn current from 185kA (current NuMI) to 250kA.

CPV sensitivity with smaller backgrounds

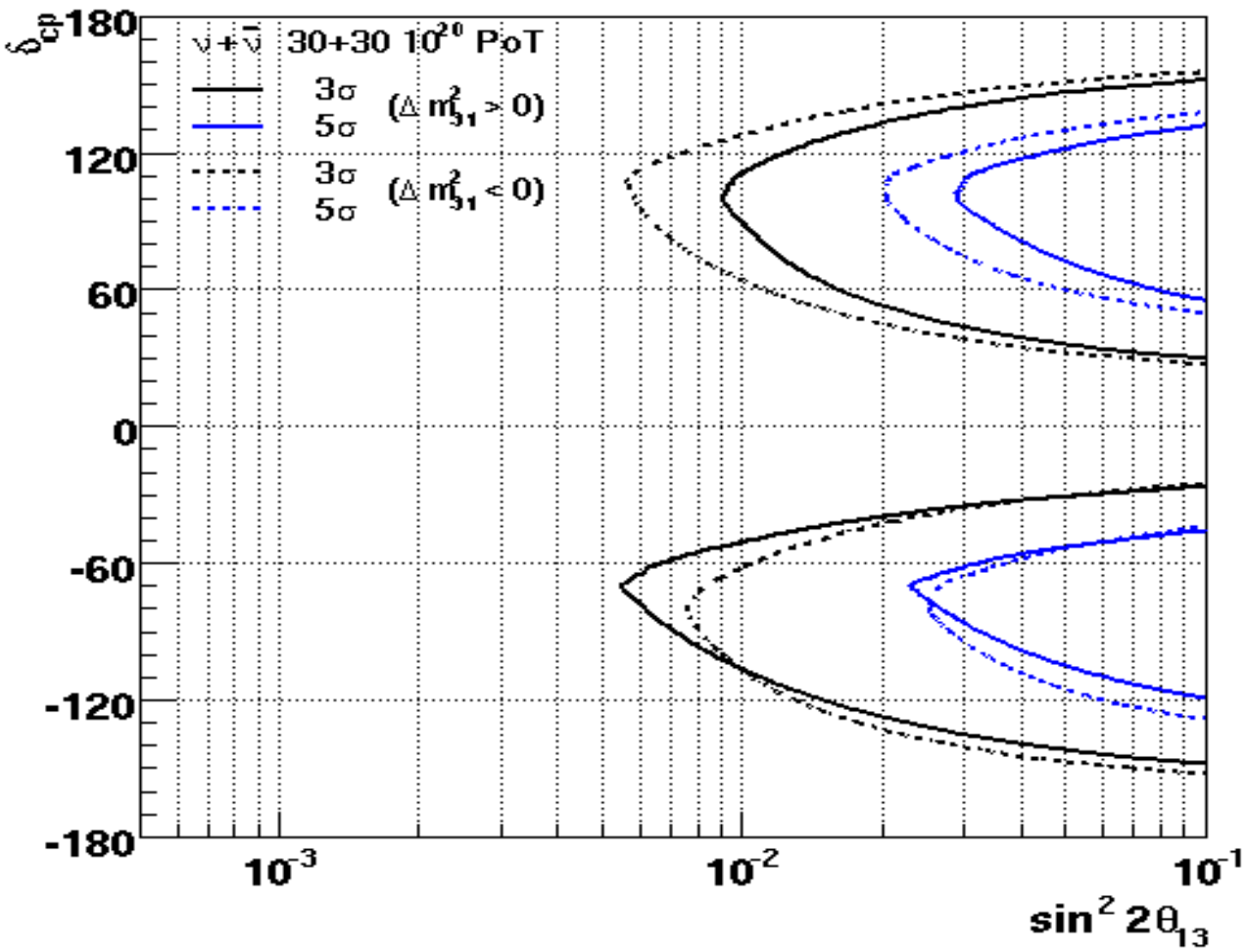
Mark Dierckxsens



Sensitivity with std background, 10% uncertainty

CPV sensitivity with smaller backgrounds

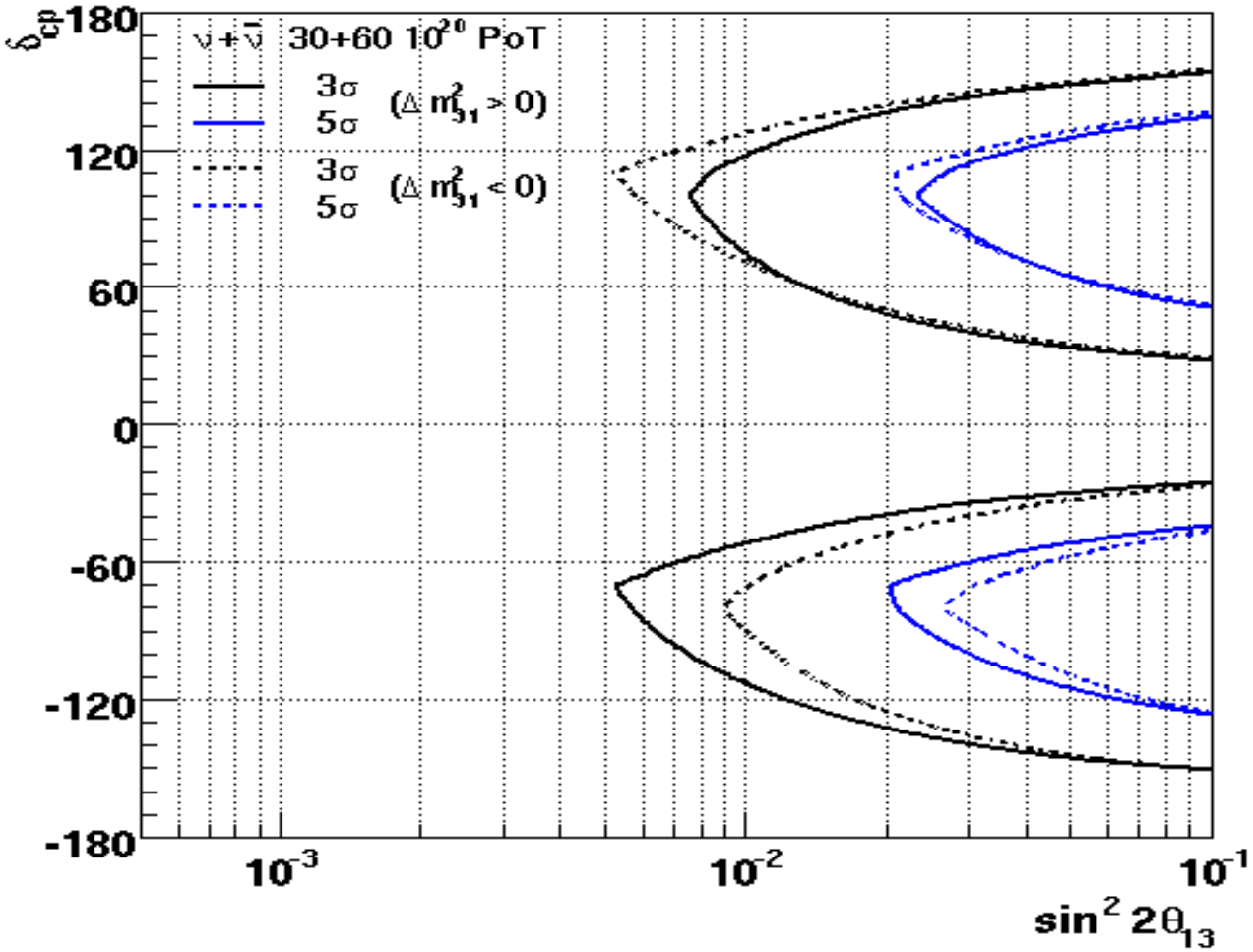
Mark Dierckxsens



Sensitivity with 1/2 background, 10% uncertainty

CPV sensitivity with smaller backgrounds

Mark Dierckxsens



Sensitivity with default background, 10% uncertainty, double $\bar{\nu}$ exposure

CPV sensitivity with smaller backgrounds

Mark Dierckxsens

For CPV sensitivity

1/2 background $\sim \bar{\nu}$ exposure $\times 2 \equiv$ 3 MW.yrs